Fermilab

Particle Physics Division
Mechanical Department Engineering Note

Number: MD-ENG-105 Date: 6/13/06

Project Internal Reference:

Project: DECAM

Title: Multi-CCD Test Vessel, Cold Finger Analysis

Author(s): Herman Cease

Reviewer(s):

Key Words: Decam, Multi-CCD Test Vessel

Abstract Summary:
The cold finger assembly includes everything from the LN2 reservoir inside the Test Vessel to the Aluminum Focal Plate. The purpose of the assembly is to cool the CCDs to -133 C (140K). The cold fingers and copper braids are sized to achieve this purpose. Analysis of the heat load and cooling capacity is given.

Applicable Codes:
N/A

INTRODUCTION:

A one dimensional hand calculation is given from the focal plate thru one cold finger, thru the cold finger assembly spreader bar, and into the LN2 bath is performed. Contact resistance at joints is considered. This analysis assumes that the heat load on the focal plate is evenly distributed among the 12 cold fingers. Contact resistance between the CCD foot and the focal plate is included. Conduction thru the CCD package is in a note by G. Derylo.

HAND CALCULATIONS:

Calculating the Radiation Heat Load Incident on the Front of the Focal Plate:

The warm front fused silica vacuum window radiates heat to the cold focal plate. The coldest desired operating temperature for the cold plate is 140K

Q= Area * emissivity surfaces * Stefan-Boltzman Constant * ($T_1^4 - T_2^4$)

Diameter of C5 lens = 0.48 meters
Area of C5 lens = 0.181 m^2

Emissivity of the both the silicon and the glass surfaces are assumed 1 for a conservative approach. In reality the silicon is about 0.85

Stefan-Boltzman constant = 5.67e-8 $W/m^2.K^4$

T_1 temperature of the glass = 260 K
A lower than ambient temperature is used due to the glass cooling due to lack of conduction to the rest of the vessel.

T_2 temperature of the focal plate = 140K in the coldest case.

Q = 0.181 * 5.67e-8 * (260^4 -140^4) = 43 W

Additional heat from the cables and electronics is expected to be ~10 watts
Total Heat Load on the focal plate ~ 55 Watts

An additional ~50 Watts cooling capacity is used so that reasonable cool down times to 140K can be achieved.

Total Heat load on cooling system is ~112 Watts

Calculating the Temperature Gradient thru the Cold Finger:

Boundary conditions:
a) Temperature at the base of the CCD package is -133 C (140 K), which is the coldest desired operating temperature for the CCDs.
b) Cooling provide by LN2 Bath (77 K) in the internal surface of the LN2 reservoir.

The heat load incident on the focal plate up thru the heaters on the cold fingers is 55 watts. Each heater adds an additional 4 Watts. The total heat load thru the cold fingers including the heaters is 103 Watts. Additional heat loading due to radiation is added where the cold fingers join the spreader bars and LN2 reservoir. The total heat load on the LN2 reservoir is 112 Watts. The temperature drop and material cross section is given for each calculated Section of the Cold Finger Assembly. Figures 1, 2 and 3 are illustrations that describe the different sections of the thermal path. Table 1 shows temperatures calculated at each section of the thermal path.

Table 1. Calculation of Temperatures at Cold Finger Joints:

	Alum-invar joint 0.3" x 1.18" at focal plate		
		200.0	h*= watts/m^2·K convection coefficient.
		0.00046	m^2 surface area cu to Cu
dT		133.0	K Temp of cold side joint
7.7		140.6	K temp warm side joint
	Q	0.7	Watts
	Section 0 Aluminum focal plate 20.5" diam x 1.38"		
		235.0	k=watts/m.K for alum 1100-O
		0.21294	m^2 surface area thru holder
		0.03505	m length
dT		132.9	K at cold finger
0.04		133.0	K far end, near ccd foot
	Q	55.0	Watts
	Section 1 Alum-Alum joint 0.263" x 2" at focal plate with brass foil insert		
		4542.4	h*= watts/m^2·K convection coefficient.
		0.00034	m^2 surface area cu to Cu
dT		129.9	K Temp of cold side joint
3.0		132.9	K temp warm side joint
	Q	55.0	Watts

	Section 2 Aluminum 0.263" x 0.25" x 2"		
		235.0	k=watts/m.K for alum 1100-O
		0.00034	m^2 surface area thru holder
		0.00635	m length
dT		129.6	K near end of al finger
0.4		129.9	K far end of al finger
	Q	55.0	Watts
	Section 3 Kapton glue break 0.375" x 1" x 0.002"		
		0.15	k=watts/m.K for kapton
		0.00024	m^2 surface area thru holder
		0.00005	0.002" thickness (length)
dT		123.2	K near end of break
6.4		129.6	K far end of kapton break
	Q	55.0	Watts
	ADDITIONAL HEATER		
	Q	4.00	Watts spread over 12 coldfingers
	Section 4 Cu 0.375" x 1"x 0.75"		
		420.0	k=watts/m.K for OFHC Cu
		0.00024	m^2 surface area thru holder
		0.019	m length
dT		121.5	K near end of al finger
1.6		123.2	K far end of al finger
	Q	103.0	Watts
	Section 5 Cu 0.375"x 0.5" x 2."		
		420.0	k=watts/m.K for OFHC Cu
		0.00012	m^2 surface area thru holder
		0.0508	m length
dT		113.0	K near end of al finger
8.6		121.5	K far end of al finger
	Q	103.0	Watts
	Section 6 Copper Braid 0.375" x 0.375" x 1.9" (50%void)		
		420.0	k=watts/m.K for OFHC Cu
		0.000045	m^2 surface area thru holder
		0.04826	m length
dT		91.2	K near end of finger
21.7		113.0	K far end of cu finger
	Q	103.0	Watts
	Section 7 Copper-Copper joint 0.375" x 1.5"		
		6245.8	h**= watts/$m^2 \cdot K$ convection coefficient.
		0.00036	m^2 surface area cu to Cu
dT		87.4	K Temp of cold side joint

3.8		91.2	K temp warm side joint
	Q	103.0	Watts
	Section 8 Cu spreader bar 0.375" x 2" x 4" * 4 quadrants		
		420.0	k=watts/m.K for Cu
		0.00194	m^2 surface area thru holder
		0.15	m length
dT		85.7	K near end of spreader
1.7		87.4	K far end of cu spreader
	Q	112.0	Watts
	Section 9 Thru Cu holder that holds stainless vessel		
		420.0	k=watts/m.K for Cu
		0.00684	m^2 surface area thru holder
		0.019	m wall thickness
dT		84.9	K inside temp of cu holder
0.7		85.7	K outside temp of cu holder
	Q	112.0	Watts
	Section 10 Thru Stainless vessel Wall		
		14.0	k=watts/m.K for stainless
		0.01026	m^2 surface area LN2 to SS
		0.00318	m wall thickness
dT		82.5	K inside temp of stainless
2.5		84.9	K outside temp of stainless
	Q	112.0	Watts
	Section 11 LN2 to stainless surface		
		2000.0	h**= watts/m^2·K convection coefficient.
		0.010	m^2 surface area LN2 to SS
dT		77.0	K Temp of LN2
5.5		82.5	K temp of SS
	Q	112.0	Watts

* Conductance thru a joint referenced from "Handbook of Heat Transfer"
** LN2 convection coefficient referenced from "The Nucleate and Film Boiling Curve of Liquid Nitrogen at one Atmosphere"

To raise the focal plate temperature from 130K to 150 K, the 12 heaters need to be increased from a total of an additional 50 Watts to a total of an additional 100 Watts.

If the heaters are left OFF, the focal plate will eventually cool to about 110 K

Variations in Cold Fingers:

The four central cold fingers have a slightly different geometry. The copper braid is slightly shorter. The shorter braid has a smaller thermal conductance, so the temperature will be about 2 degrees cooler in the middle of the focal plate. Additional heater power will be required to maintain a uniform temperature profile for all braids. Alternatively a smaller cross section of copper could be used in the central 4 braids. Since variations in the joints is expected, testing should be performed to confirm the conductance of each braid.

COOL DOWN TIMES:

An estimate of the heat capacity of the system is calculated in Table 2.

Table 2. Heat Capacity of the System:

	lbs	gms	heat capacity J/g.C	dT	Joules
Al focal plate	26	11,800	0.896	143	1,510,000
	26	11,800	0.896	153	1,620,000
Cu spreader bar	26.2	11,900	0.385	143	655,000
	26.2	11,900	0.385	153	701,000
Stainless reservoir	8	3,630	0.5	143	260,000
	8	3,630	0.5	153	278,000
Fused Silica Window	40	18,200	1	16.5	300,000
				150K	2,725,000
				140K	2,900,000

The fused silica window has an average temperature drop of 16.5 K since the edges of the window are at ambient temperature, and the central portion is at 260 K

To achieve 150 K, 2,725,00 Joules needs to be removed from the system.
To achieve 140K, 2,900,000 Joules needs to be removed from the system.

Using a cooling capacity of 100 Watts, it will take approximately 7 ½ hrs to cool the focal plate from room temperature to 150K

Using a cooling capacity of 50 Watts, it will take approximately 1 hour to cool from 150 K to 140 K.

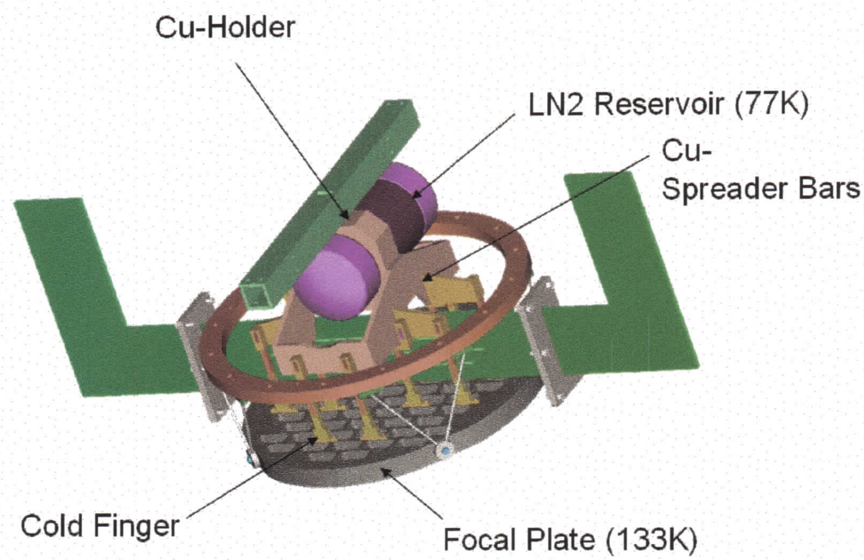

Figure 1. Cold Finger Assembly

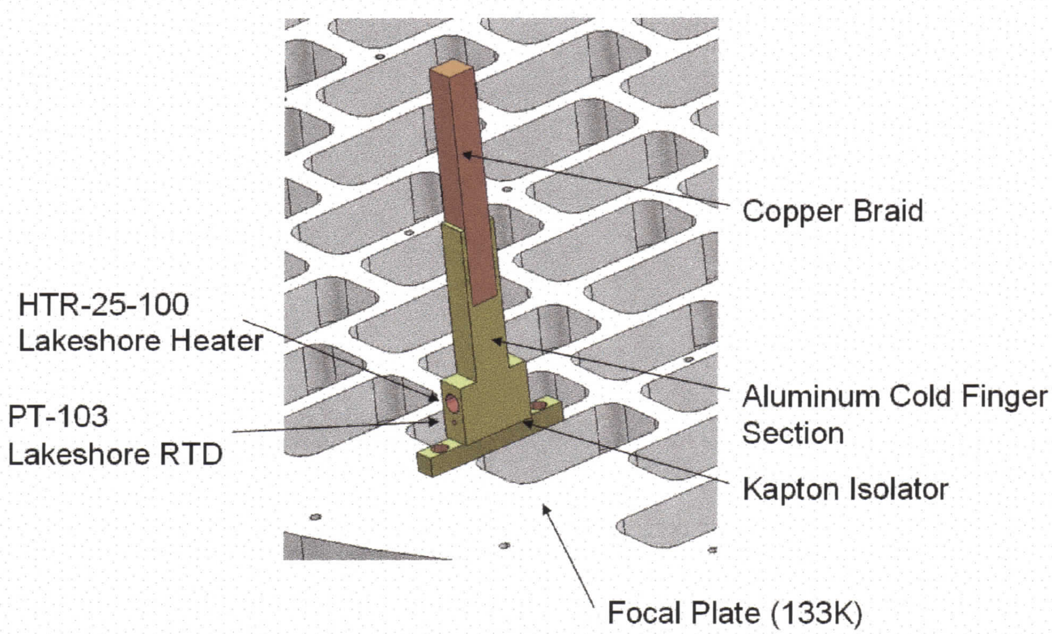

Figure 2. Cold Finger

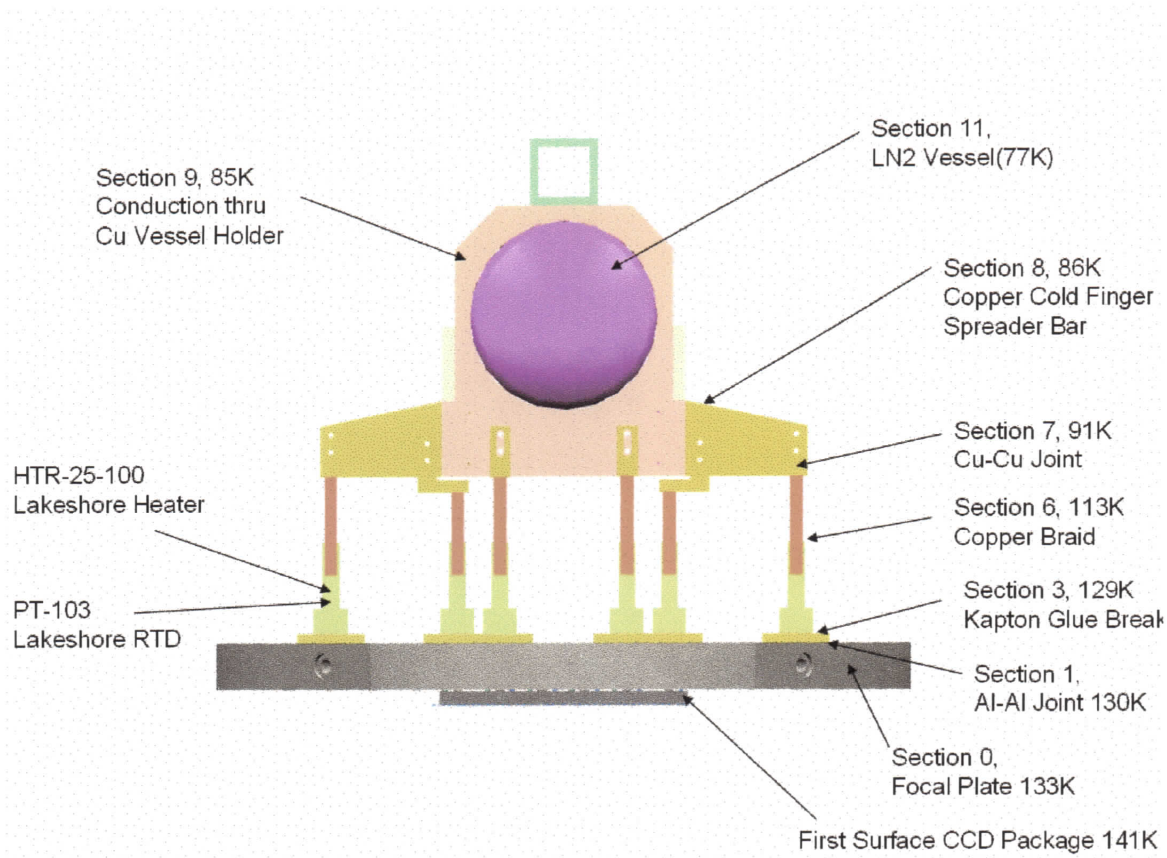

Figure 3. Cold Finger Assembly Temperatures